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- GRAY SCALE DOCUMENTS

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Figure 1. Introduction to Imaging Problems

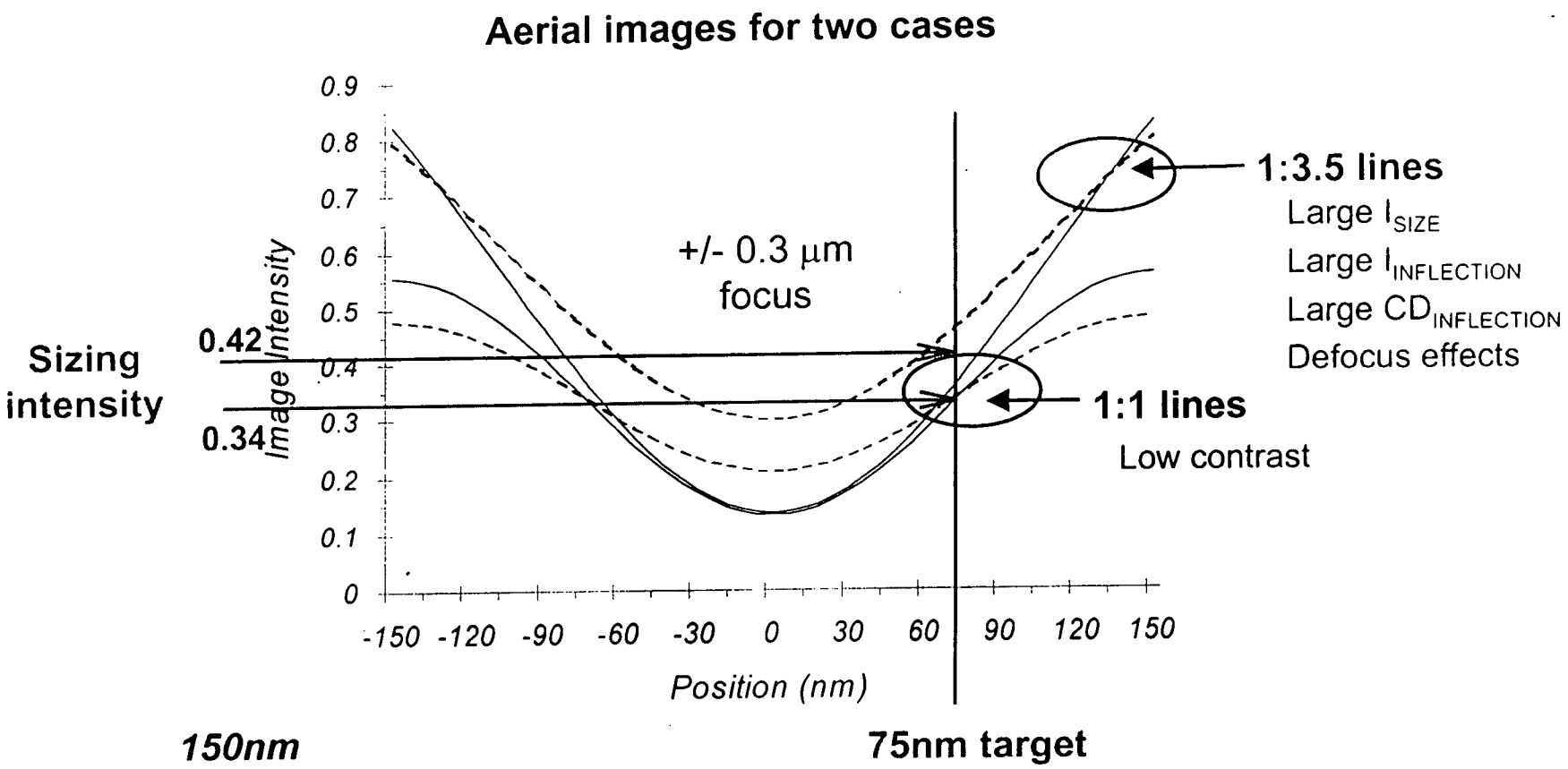
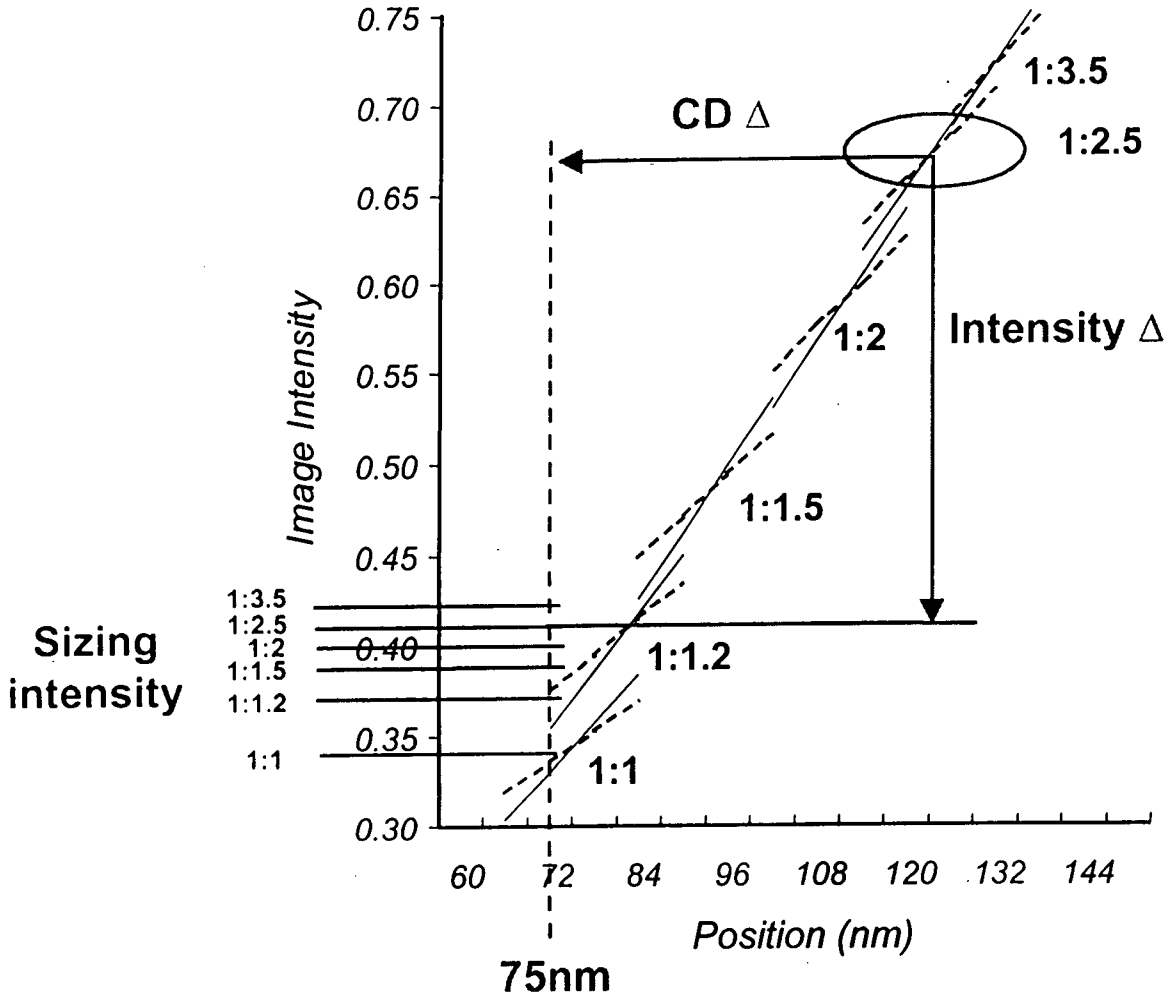


Figure 2. Key image CD/intensity locations 150nm geometry



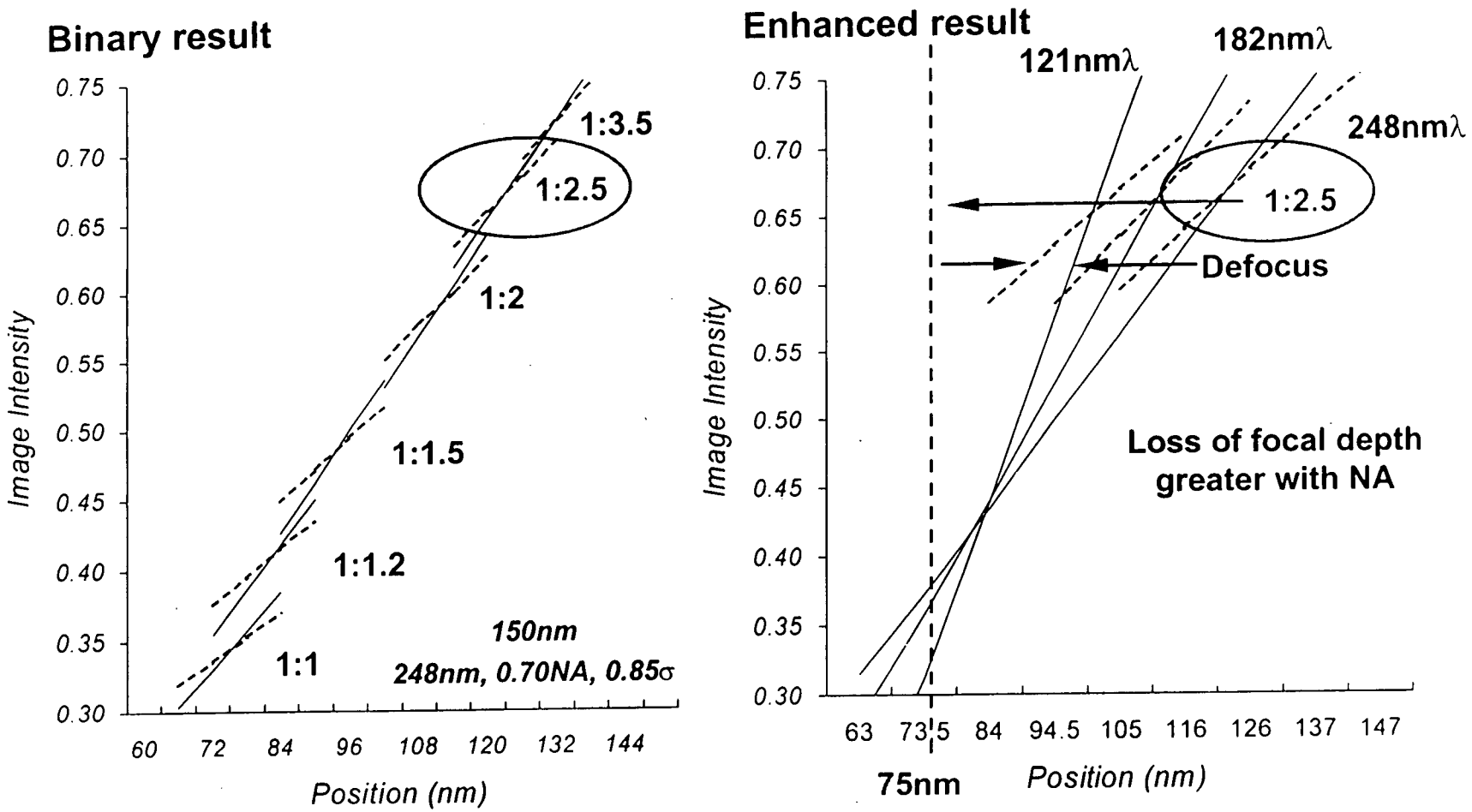
GOALS

- Increase image contrast and slope
- Drive intensity to common inflection
- Move inflection CD toward sizing CD
- Decrease across pitch differences

METHODS

- Illumination
- Object (mask)
- Frequency filtering

Figure 3. Improvements with wavelength Shift of CD with additional orders



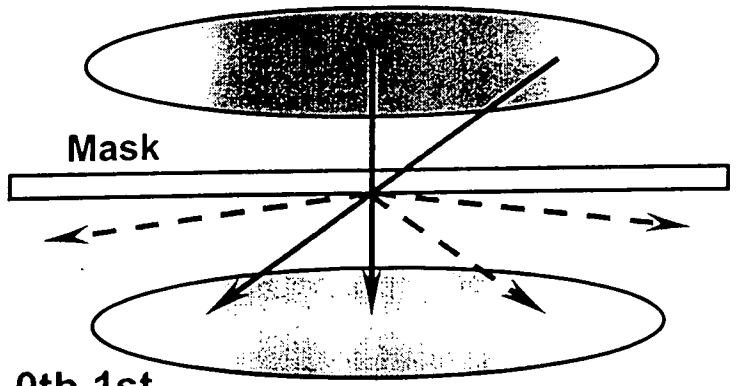
Can Image Modifications lead to improvement?

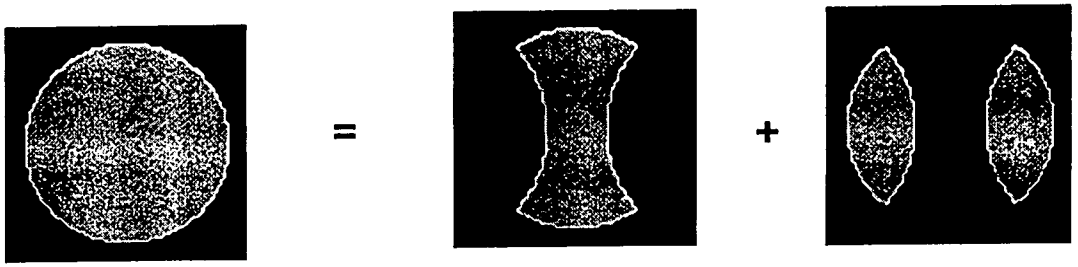
Figure 4. Image contribution for small pitch
One and *two* order imaging

Illumination can be broken down into contributing parts

There is no three-order interference with

$p < \lambda/(\sigma+1)NA$





=

+

150nm 1:1

248nm/0.7NA/
0.85σ

Full Illuminator

Zero only (one-order) contribution

Zero and 1st (two-order) contribution

Figure 5. Illumination of various pitch values

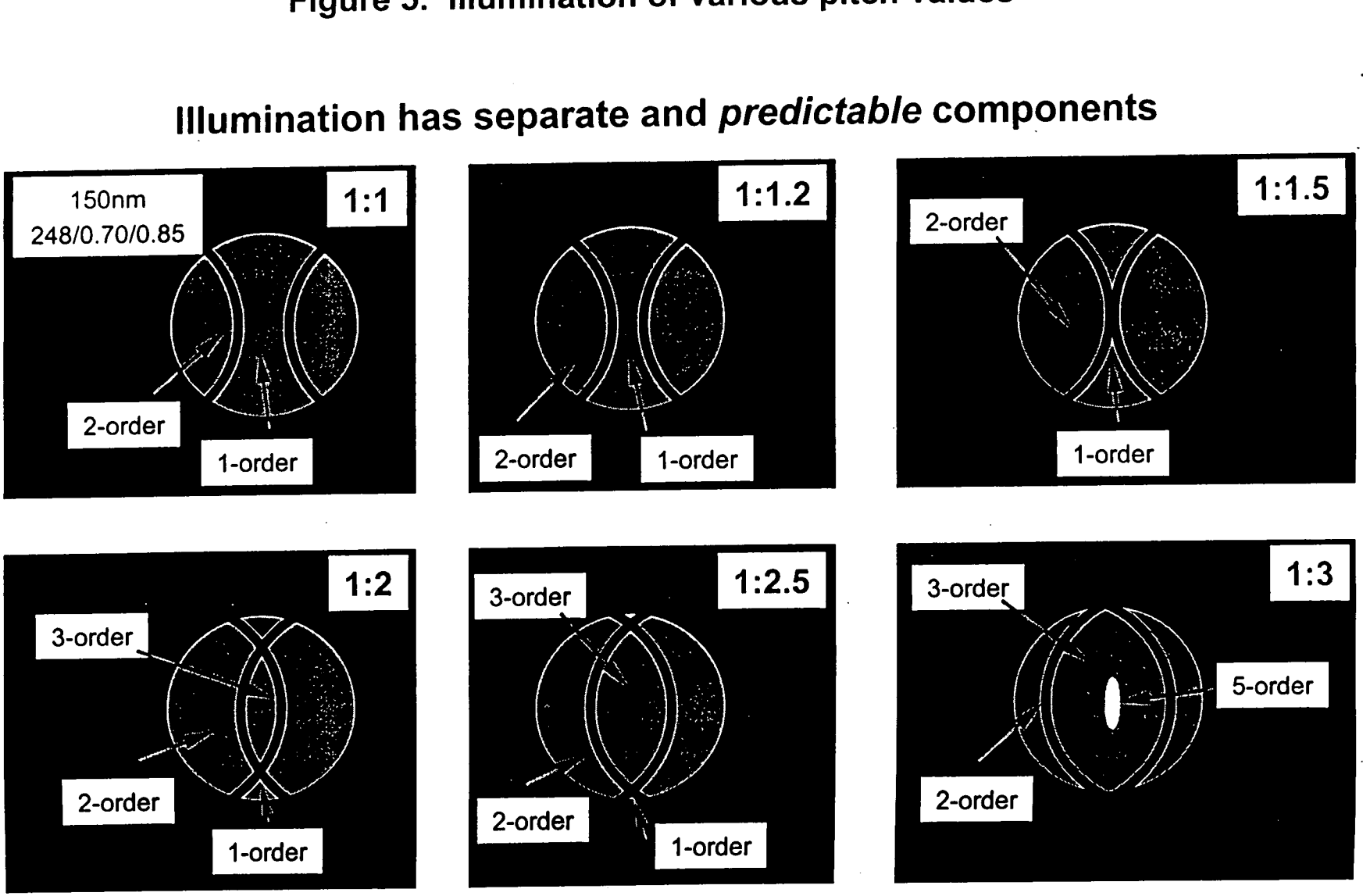
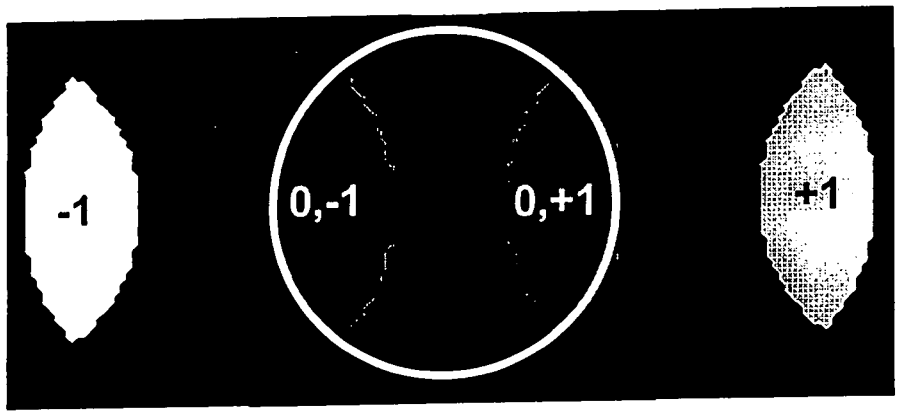
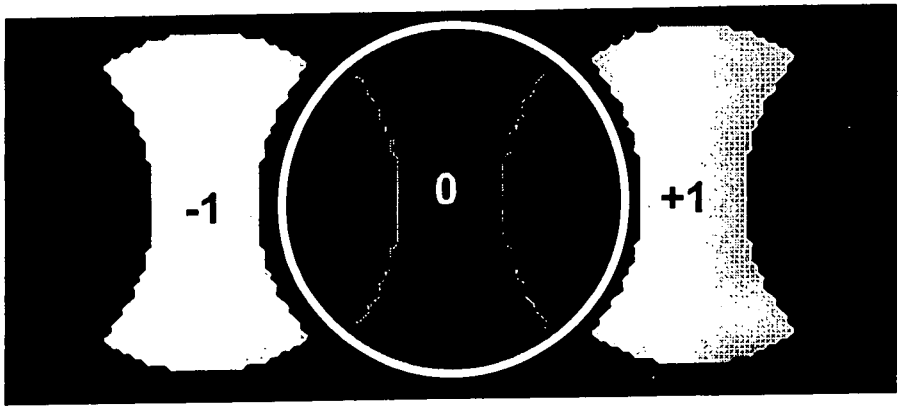


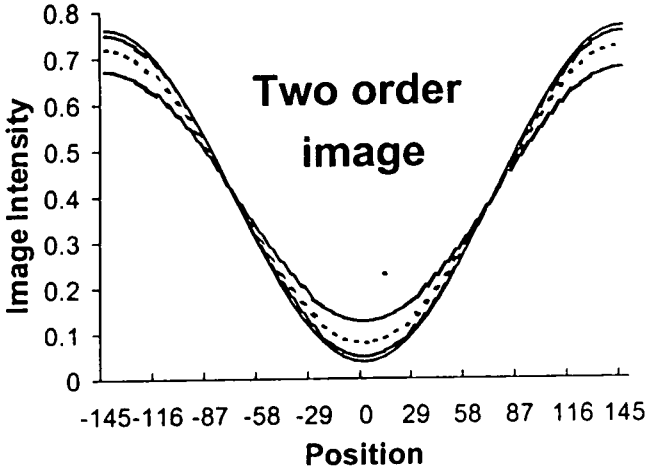
Figure 6. One and two order imaging
150nm 1:1



Pupil



Pupil



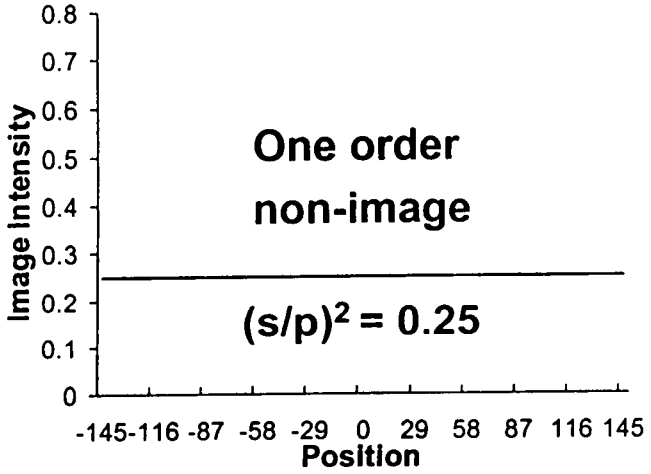
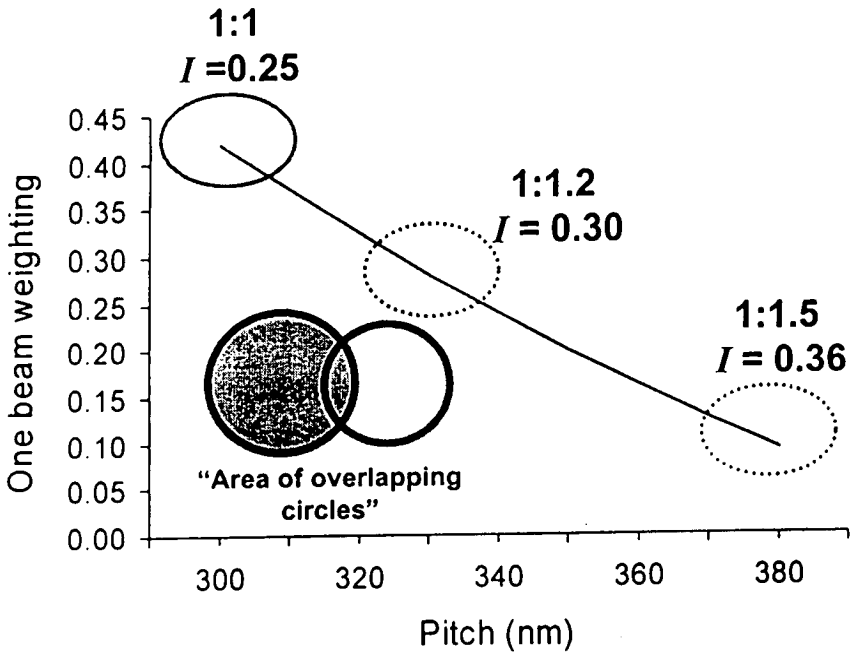
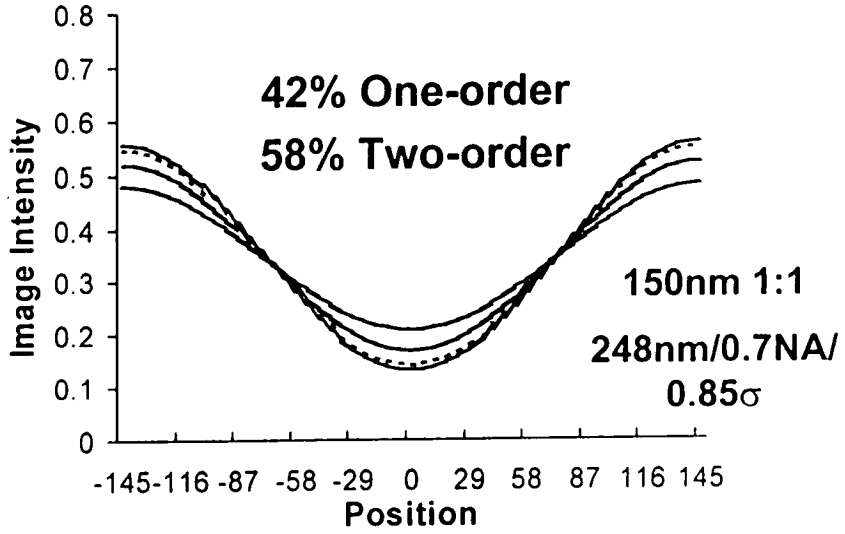


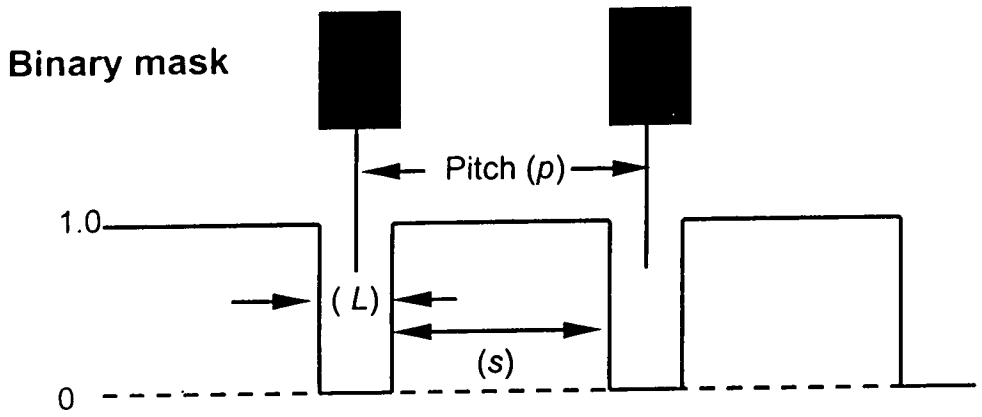
Figure 7. Image contribution - weighting of components





- 42% of the 1:1 image is one order "non-image" intensity (I) of 0.25
- Three-order imaging begins at >1:1.55 (one order dimishes)
- Illumination should be tailored to reduce non-image contribution
- *Predictable* from frequency domain

Figure 8. Mask E-field and diffraction order magnitude

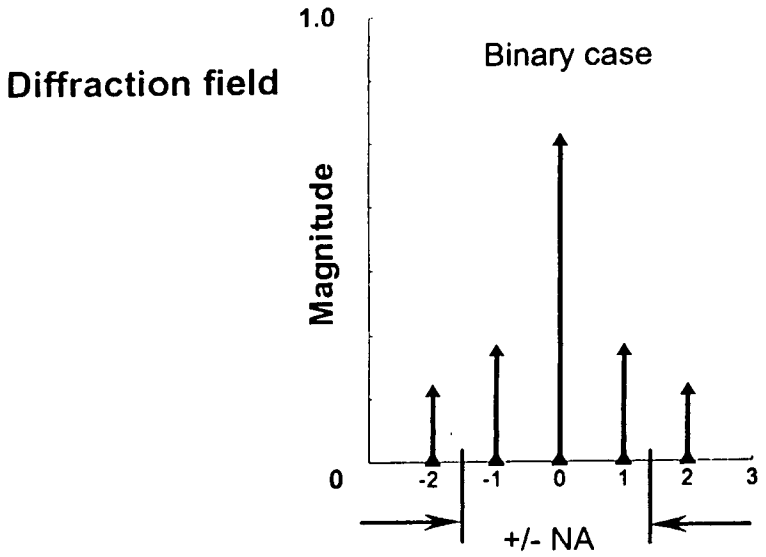


$$|\text{Mag.}|_{\text{zero order}} = (s/p)$$

$$\text{DC} = (s/p)^2$$

$$|\text{Mag.}|_{\text{first order}} = \left|\left(\frac{s}{p}\right)\text{sinc}\left(\frac{s}{p}\right)\right|$$

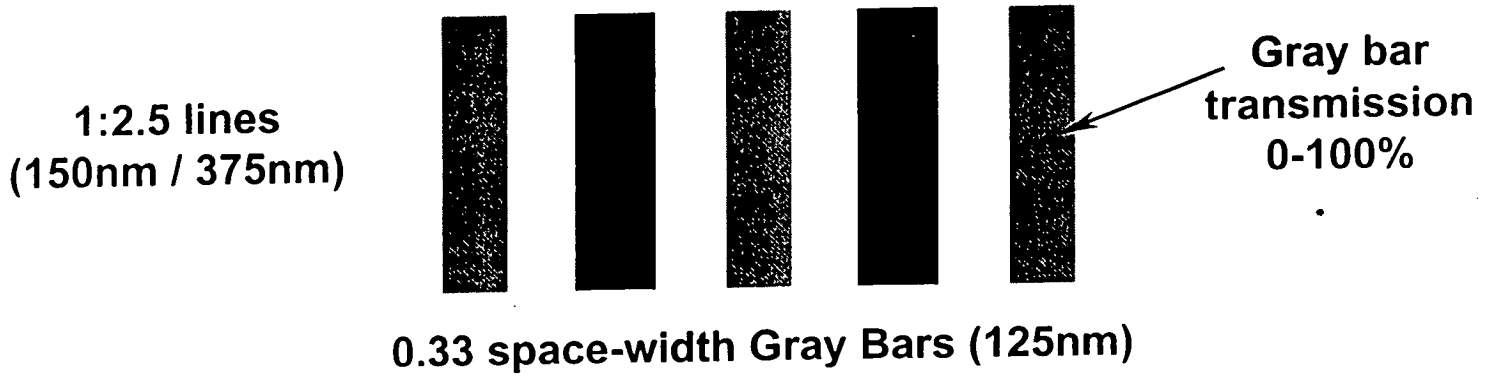
$$|\text{Mag.}|_{\text{second order}} = \left|\left(\frac{s}{p}\right)\text{sinc}\left(\frac{2s}{p}\right)\right|$$



How can the mask E-field be modified-

- **PSM**
- **Field modification**
- **More general solutions**

Figure 9. Modification of Mask E-field
The use of Gray Bars



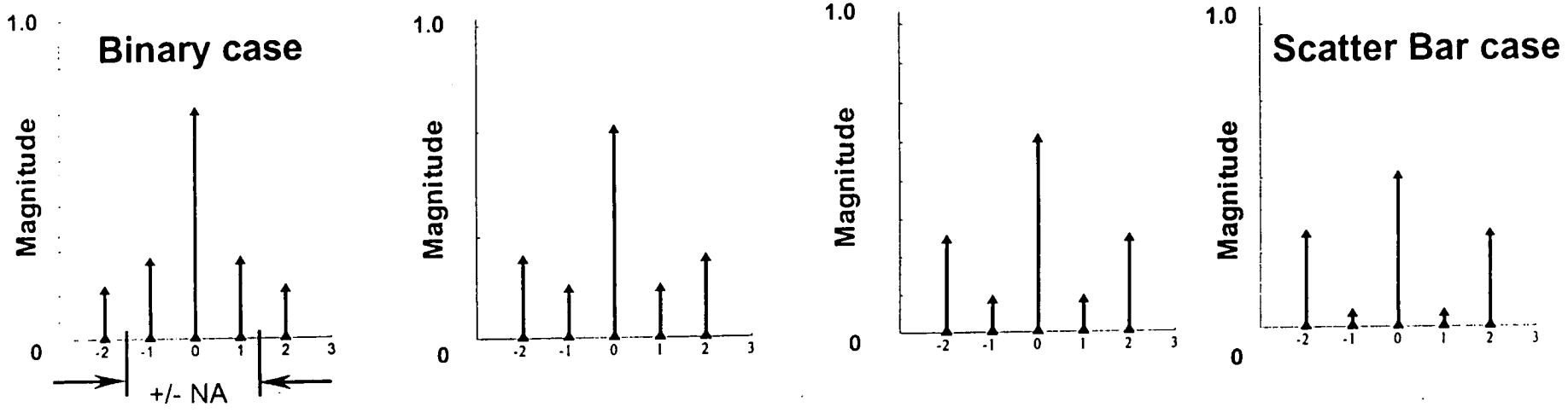
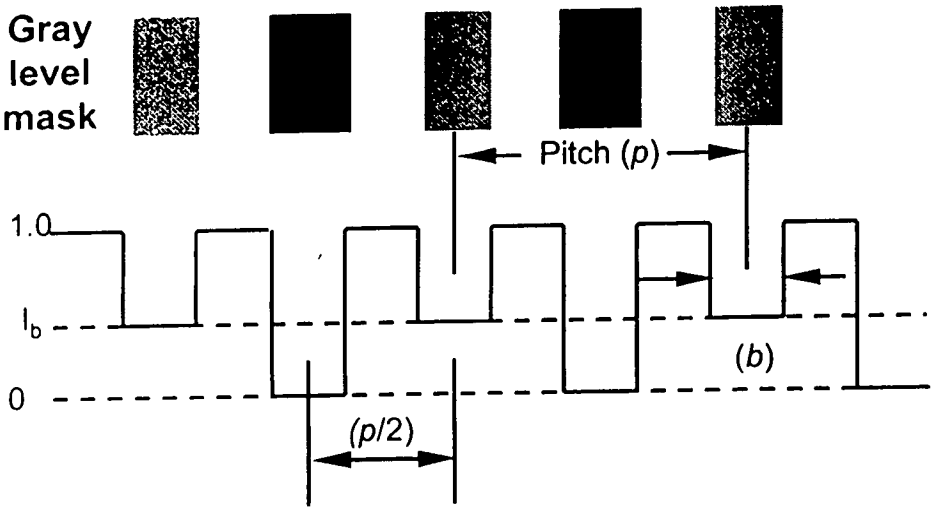


Figure 10. Mask E-field and diffraction energy with Gray Bars



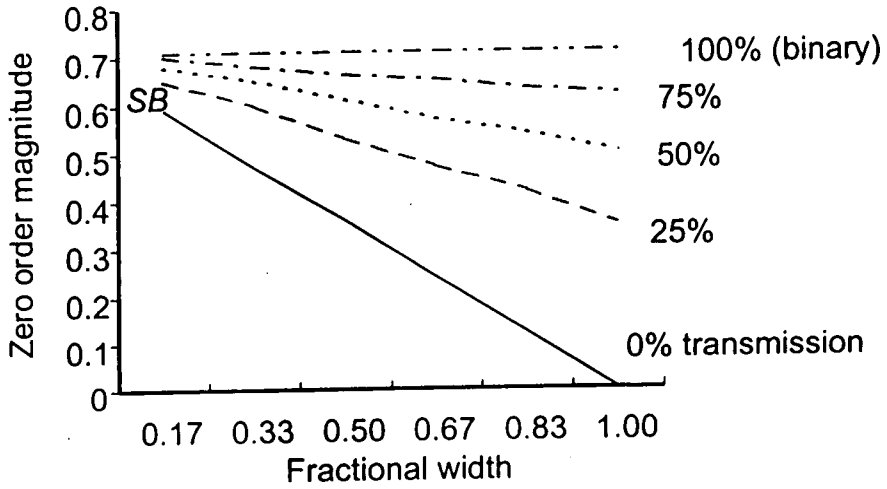
$$|\text{Mag.}|_{\text{zero order}} = [1-(\frac{b}{s})(1-\sqrt{I_b})]\cdot(\frac{s}{p})$$

$$|\text{Mag.}|_{\text{first order}} = \left|(\frac{s}{p})\text{sinc}(\frac{s}{p}) - \sqrt{I_b}(\frac{b}{p})\text{sinc}\frac{b}{p})\right|$$

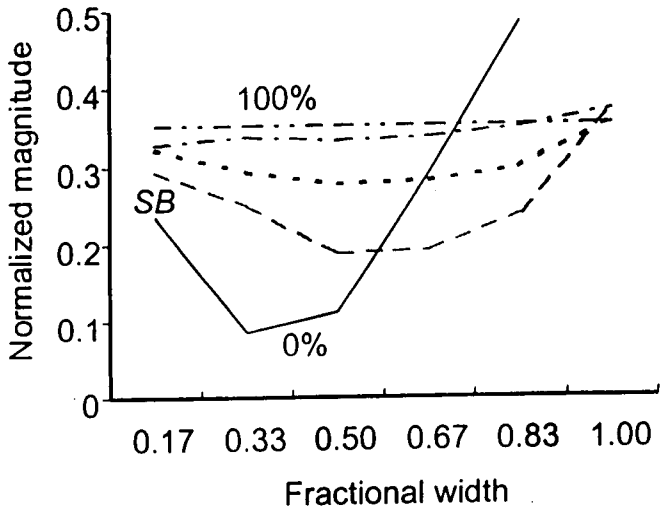
$$|\text{Mag.}|_{\text{second order}} = \left|(\frac{s}{p})\text{sinc}(\frac{2s}{p}) - \sqrt{I_b}(\frac{b}{p})\text{sinc}\frac{2b}{p})\right|$$

Figure 11. Diffraction energy control using Gray Bars

Zero order magnitude



1st order



2nd order

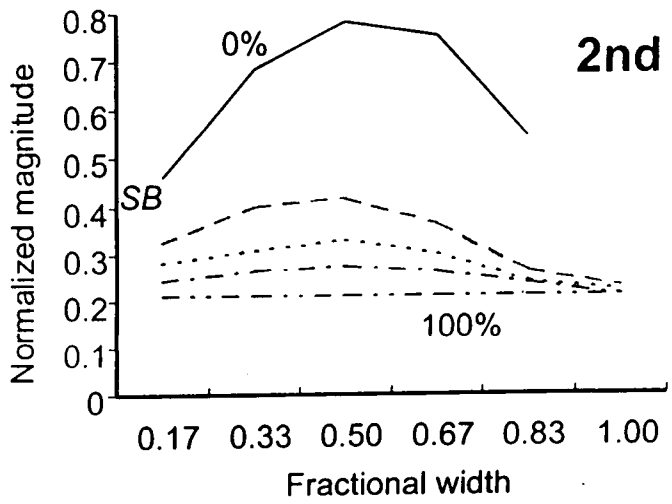


Figure 12. Equivalent solutions for Gray Bars and SBs

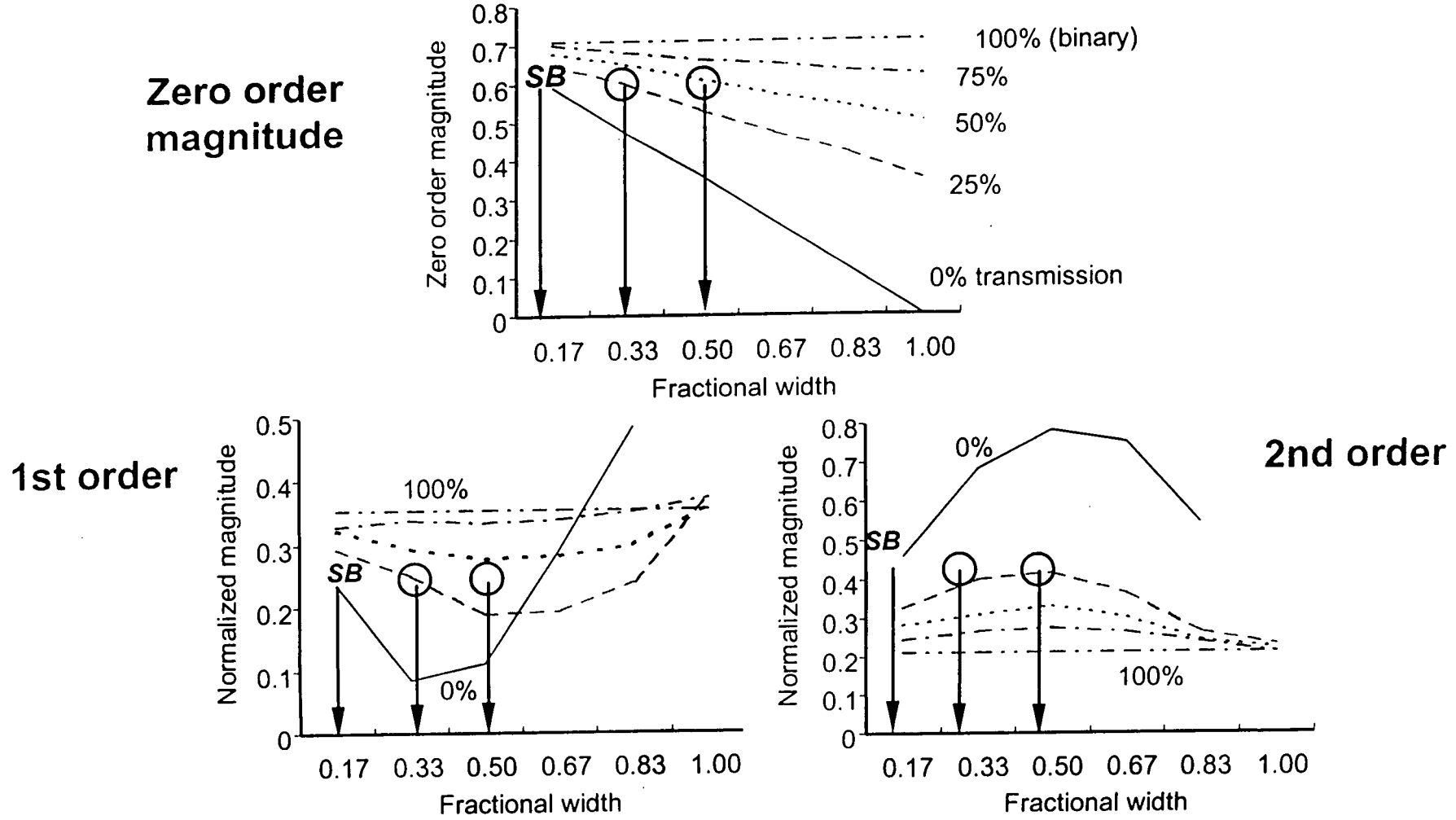


Figure 13. Comparison of Gray Bar results

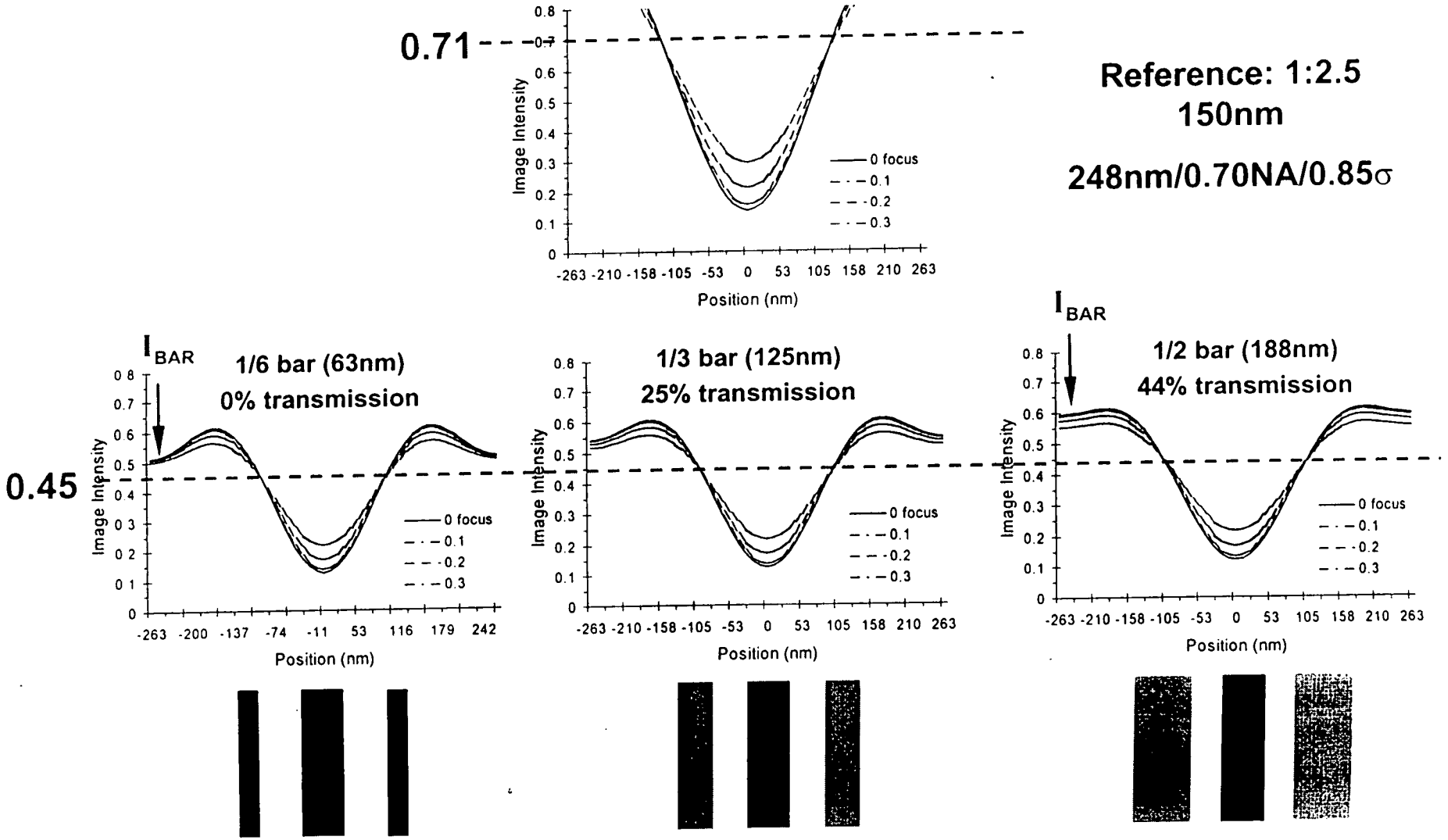
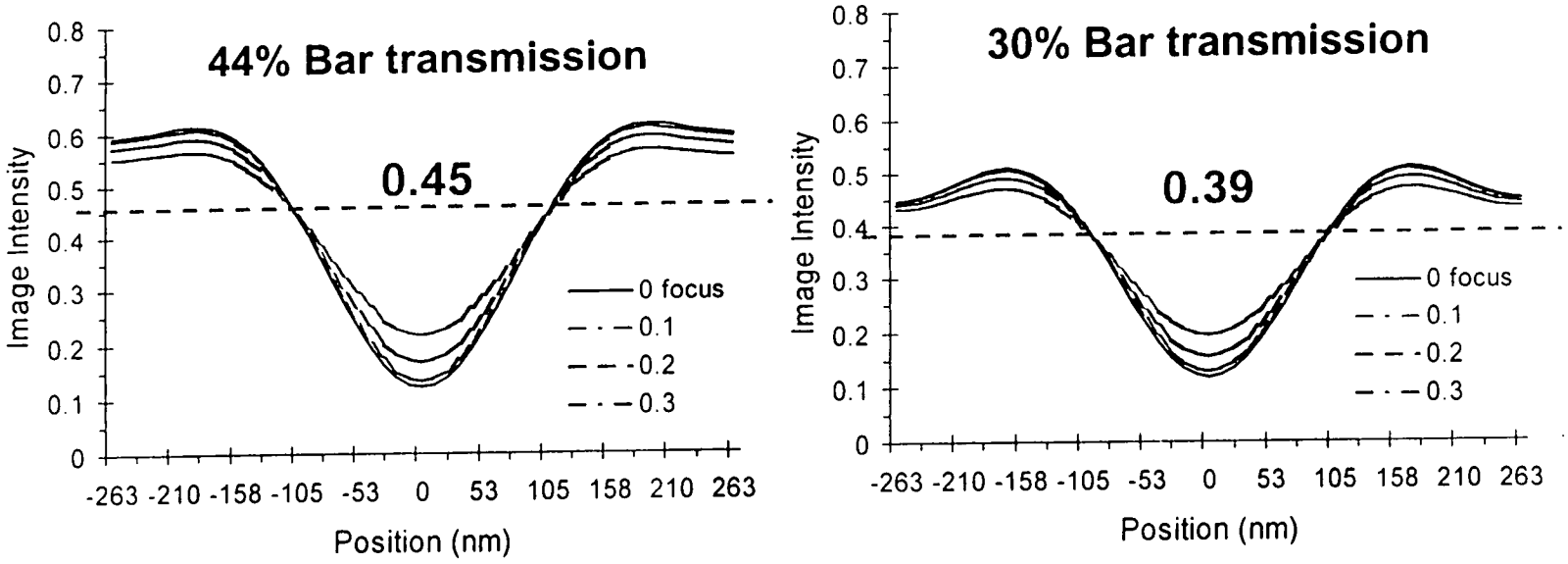


Figure 14. Gray Bar tuning

(*b*/*s*) = 1/2

188nm gray bar



- Printability of the gray bar is low because of the dampened 2nd order influence
- Gray bar sizing is practical 0.10*s* < bar < 0.7*s* ***and*** bar = 0*s* & 1*s* (mask dependant)
- Adverse OAI influence with gray bar is reduced over dark bar
- 25-50% gray bar transmission is a good general solution

Figure 15. Image CD / intensity results with Gray Bars

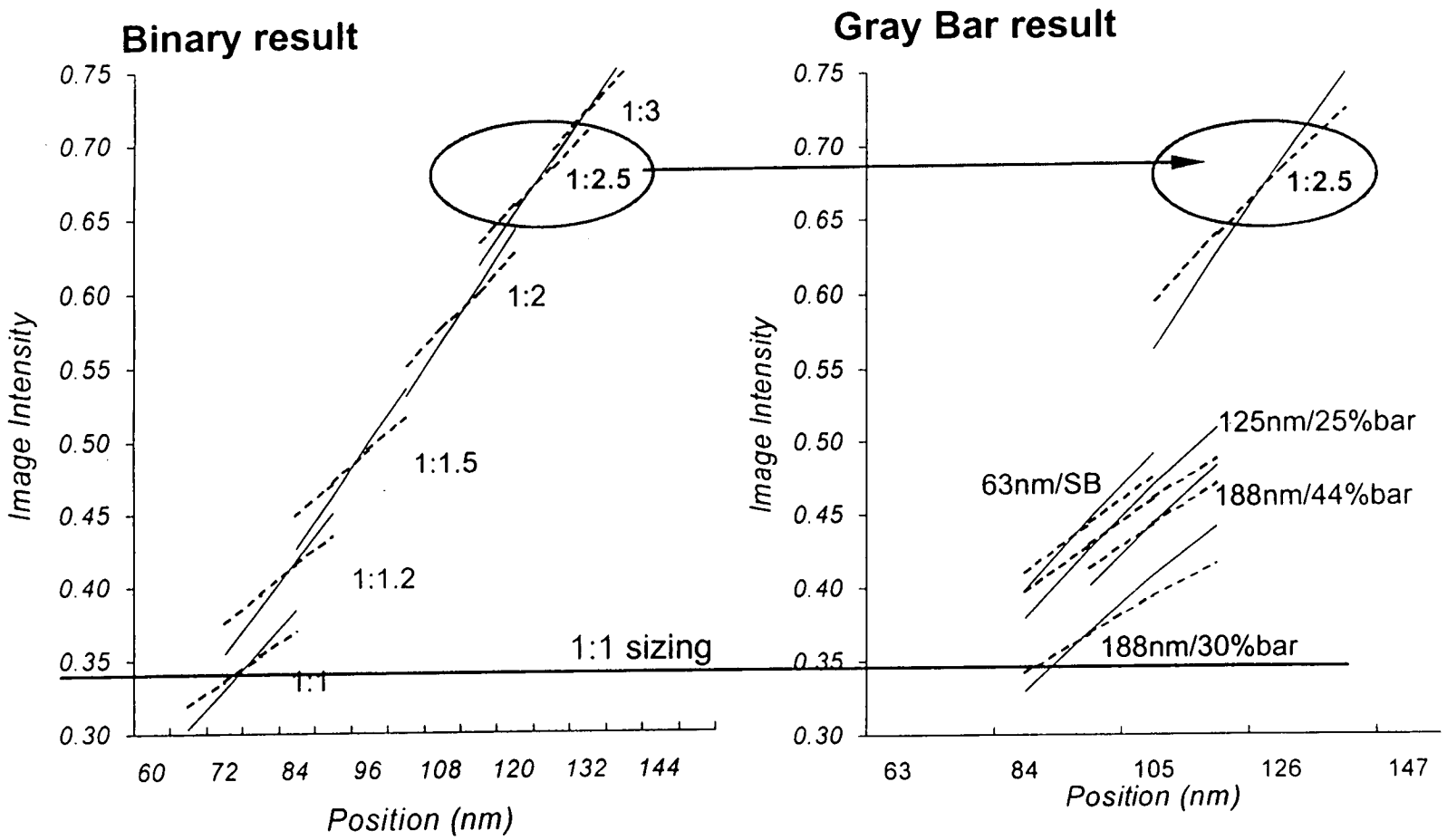
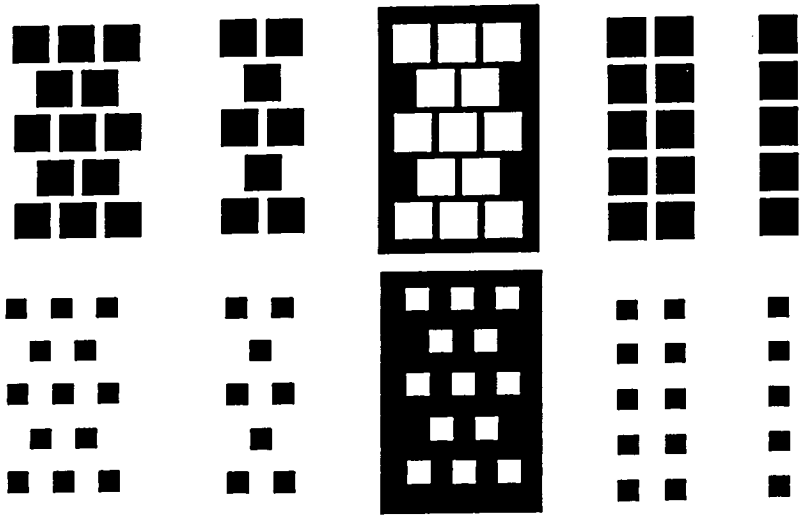
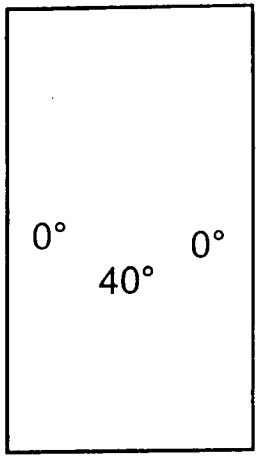


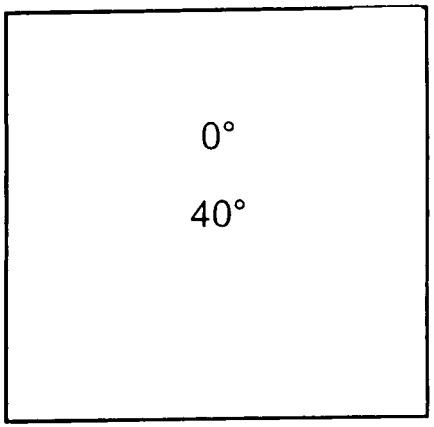
Figure 16. Gray Bar methods
Chrome or sub-π phase attenuation





Odd-bars give focus asymmetry

Even-bars give image asymmetry



Sub-π checkerboards avoid asymmetry

Island arrays

Pitch (nm)	*Transmission*
80	21%
100	45%
120	62%
140	74%

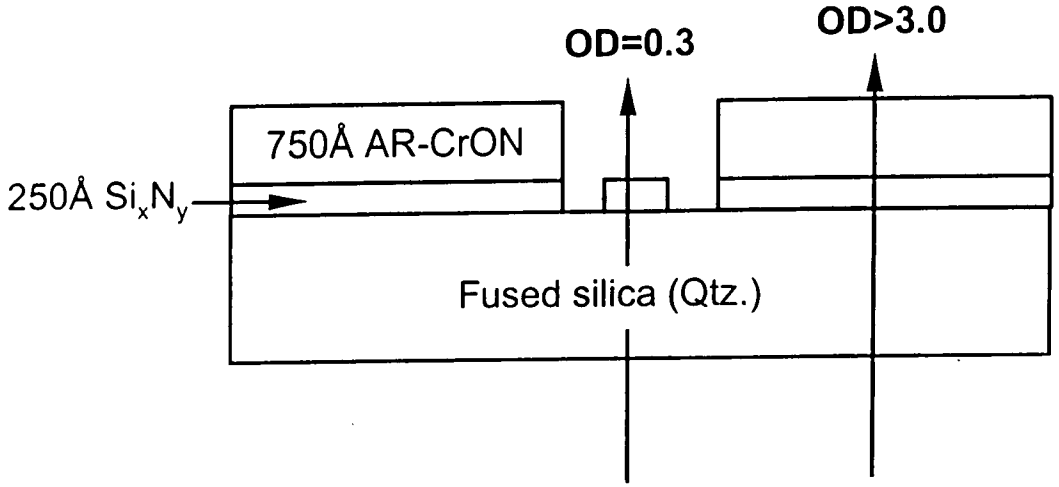
1/3 phase bar

Phase (deg)	*Transmission*
40	12%
60	25%
80	42%
100	60%

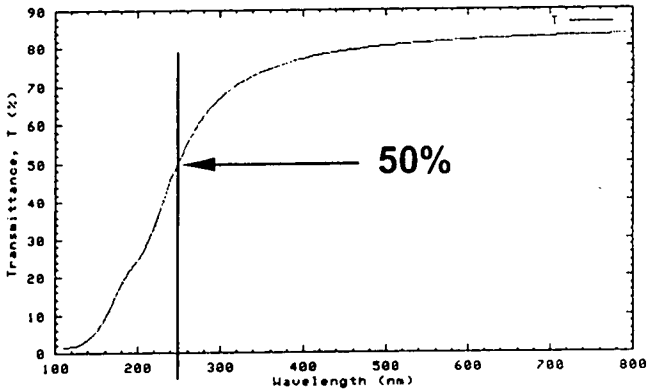
Figure 17. Gray Bar methods
Multiple level mask

Films deposited for 50% transmission

- Composite Si_xN_y at 88% Si_3N_4 with 12% Si
- Sputter deposited from Si at 1000W in Ar/N2
- Etch selectivity to CrON via SF_6-chemistry
- Sub-50% transmission via lower Si content

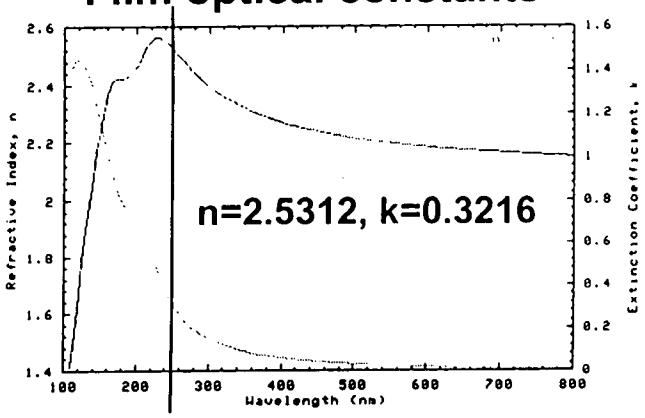


Film transmission at 250Å



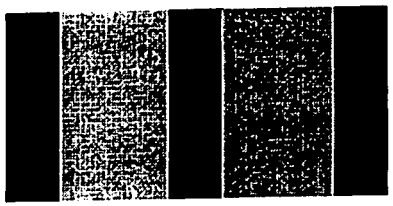
248nm

Film optical constants

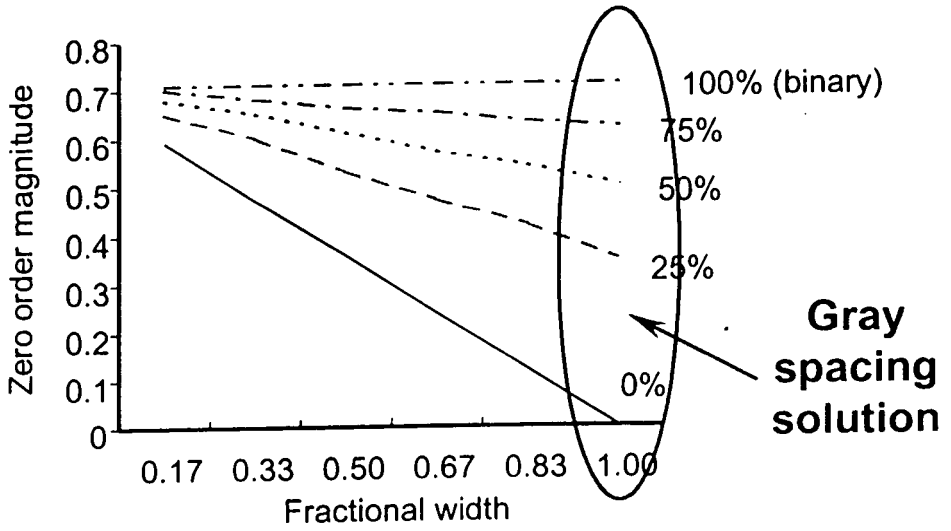


248nm

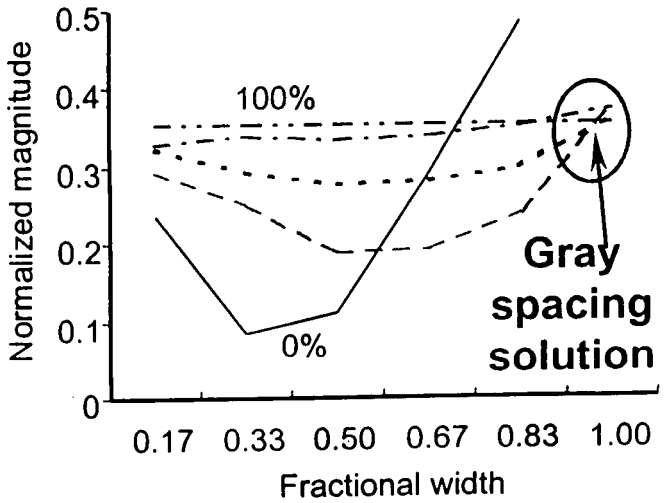
Figure 18. The problem with "gray spacing"



Sizing dose adjusted across pitch



1st order



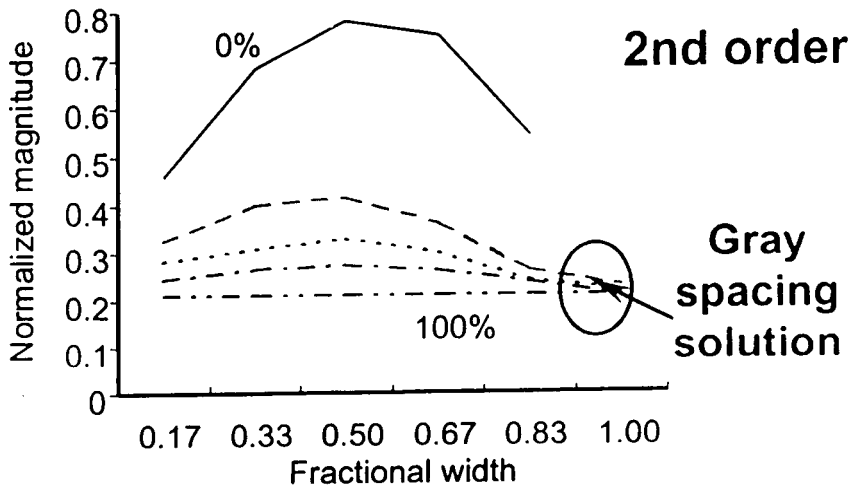
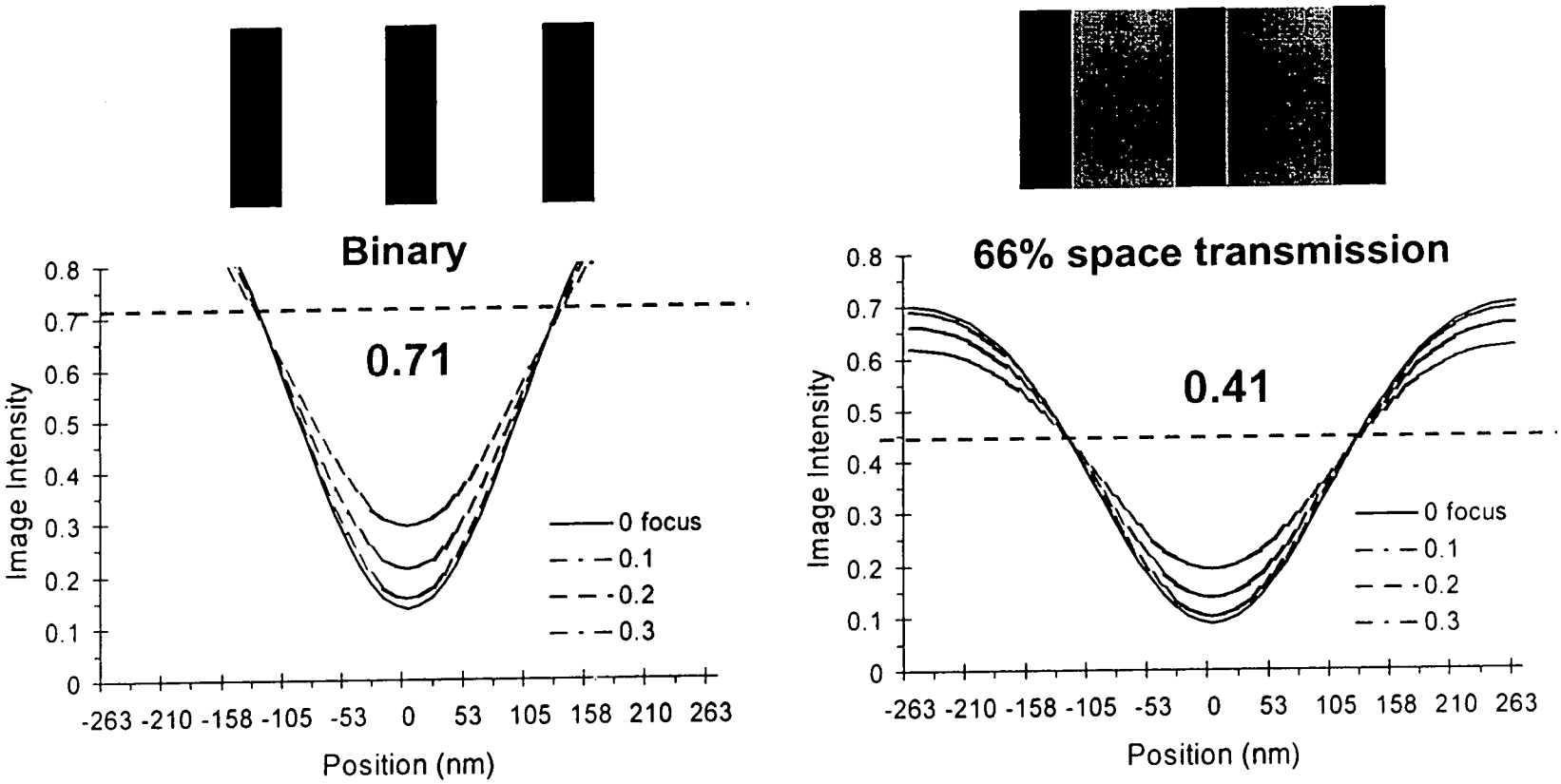


Figure 19. Gray spacing solution
Reduction in Intensity Δ



1. Uniform decrease in all orders - loss of modulation
2. Does not reduce isofocal CD to sizing delta
3. Limited solution

Figure 20. Impact of gray scaling
Reduction only in Intensity to sizing Δ

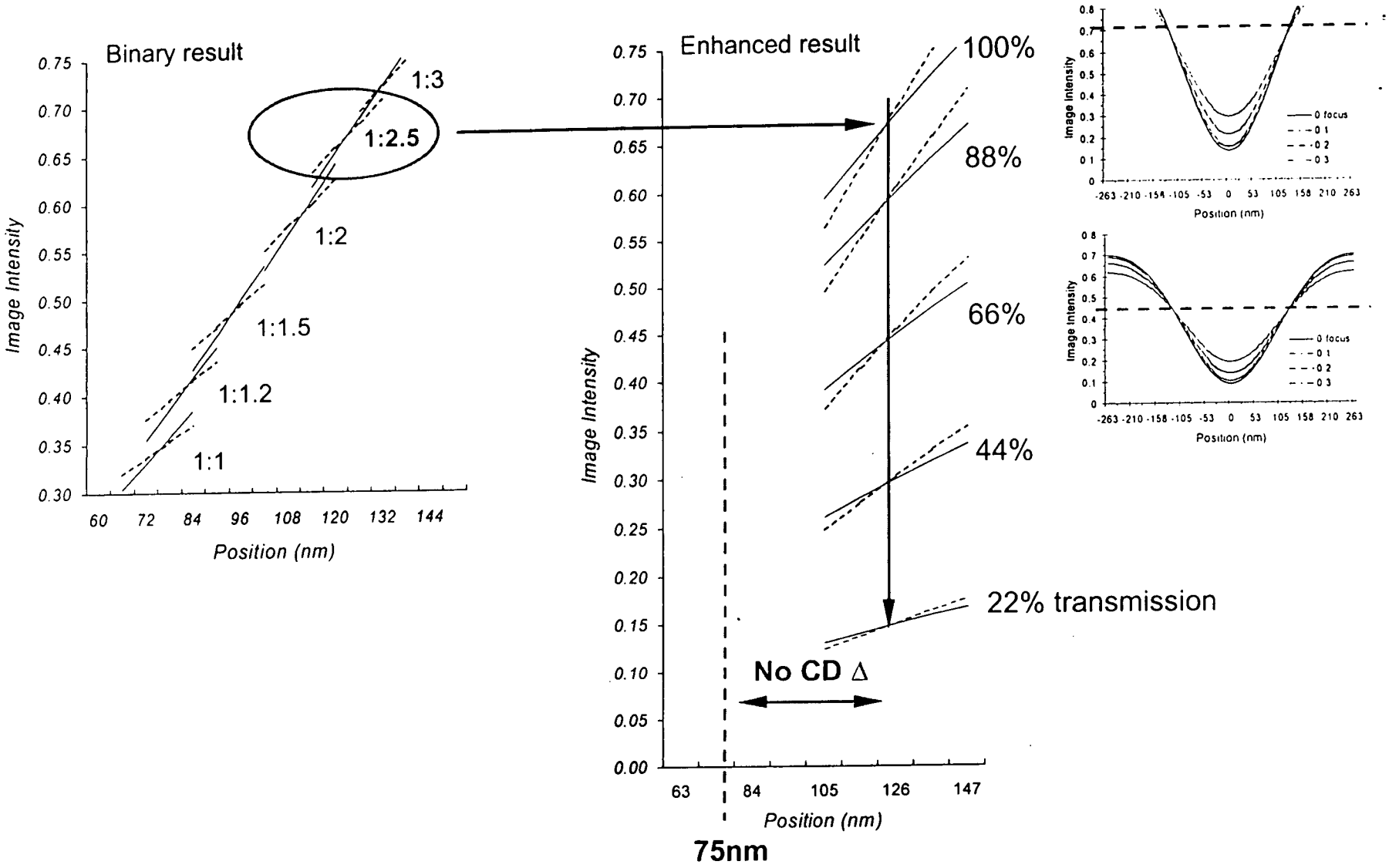
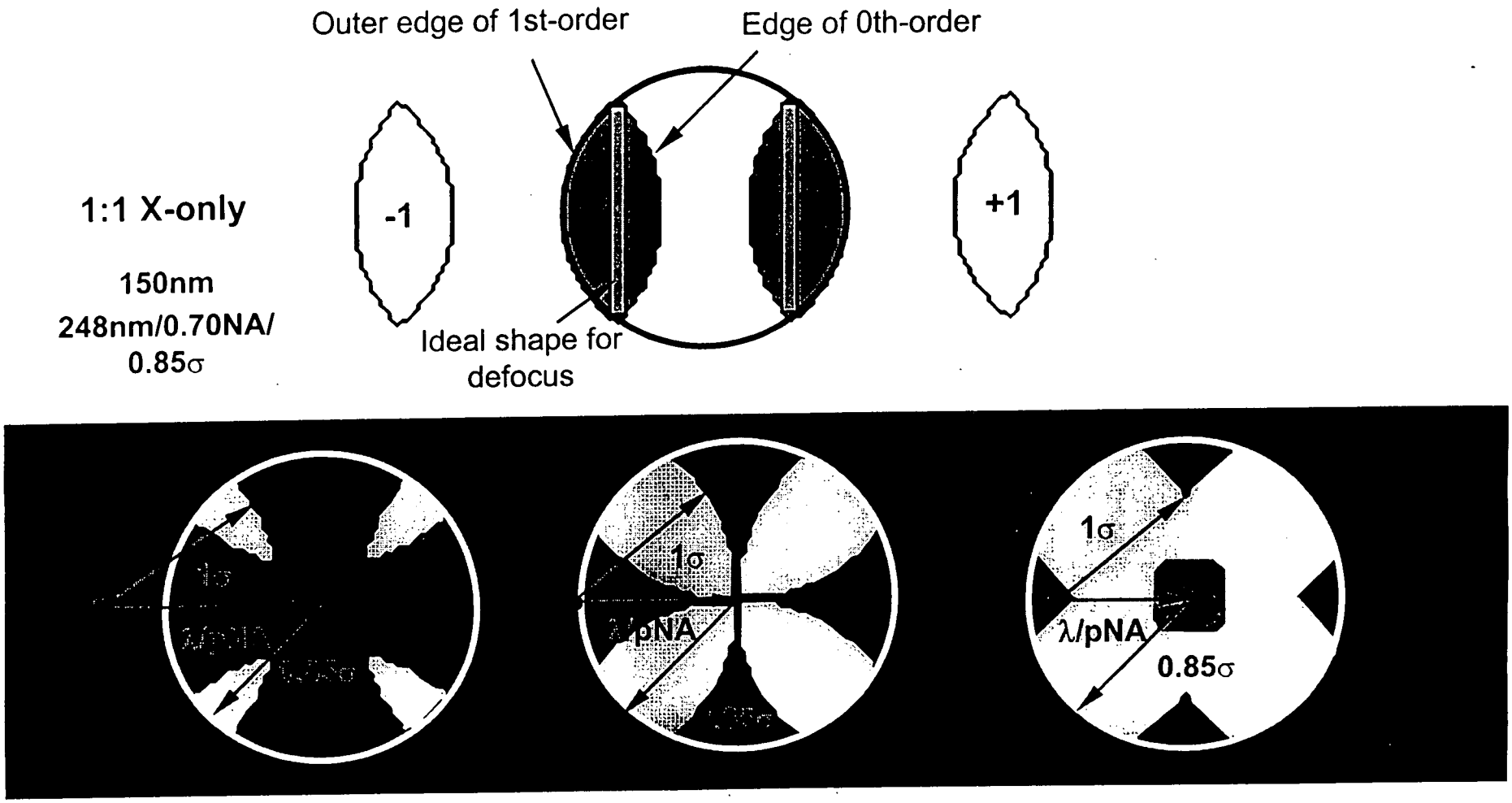


Figure 21. Illumination control of diffraction energy

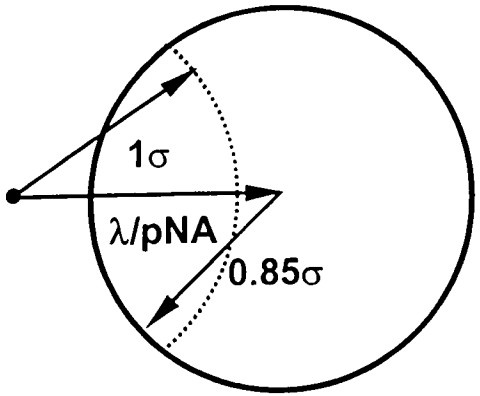


1:1 X/Y illumination

1:1.5 X/Y illumination

1:2 X/Y OAI "Problematic"

Figure 22. Custom source for dense /semi-dense features



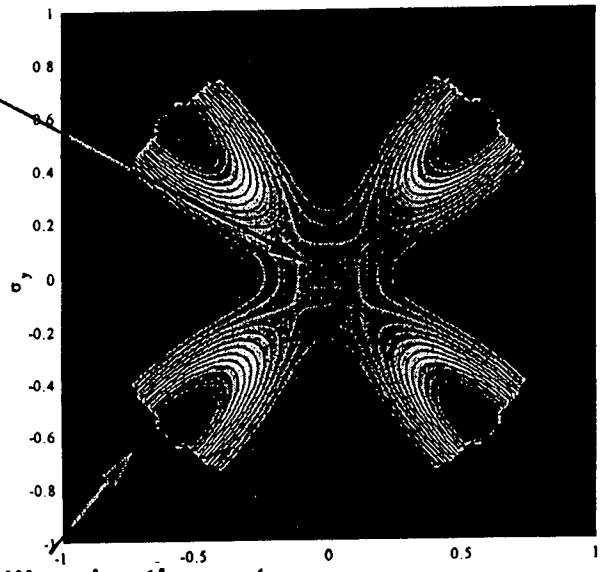
Method for layout

Parameters to define: pitch, NA, and σ

Best source for each pitch is designed

Weighting is chosen and sources are combined

Center intensity for >1:1.5



Corner illumination at 0.85σ for 1:1 to 1:1.5

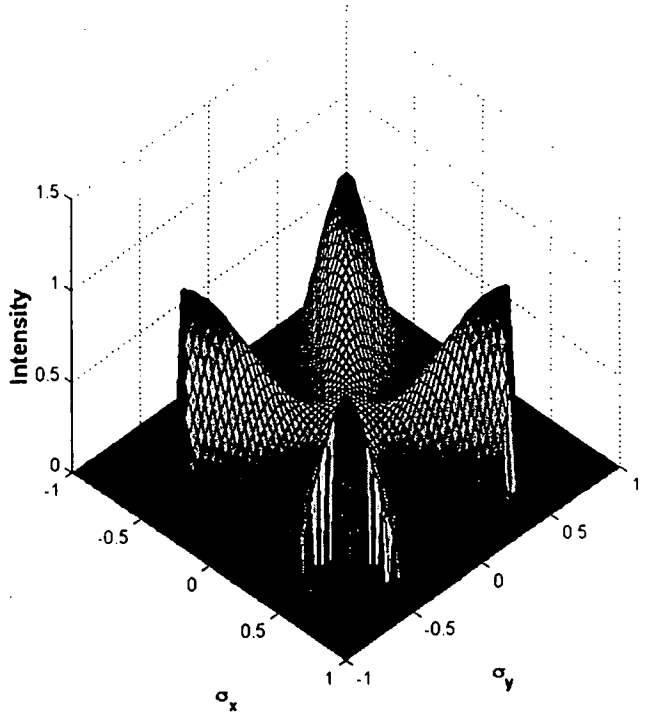


Figure 23. Image results with the custom source

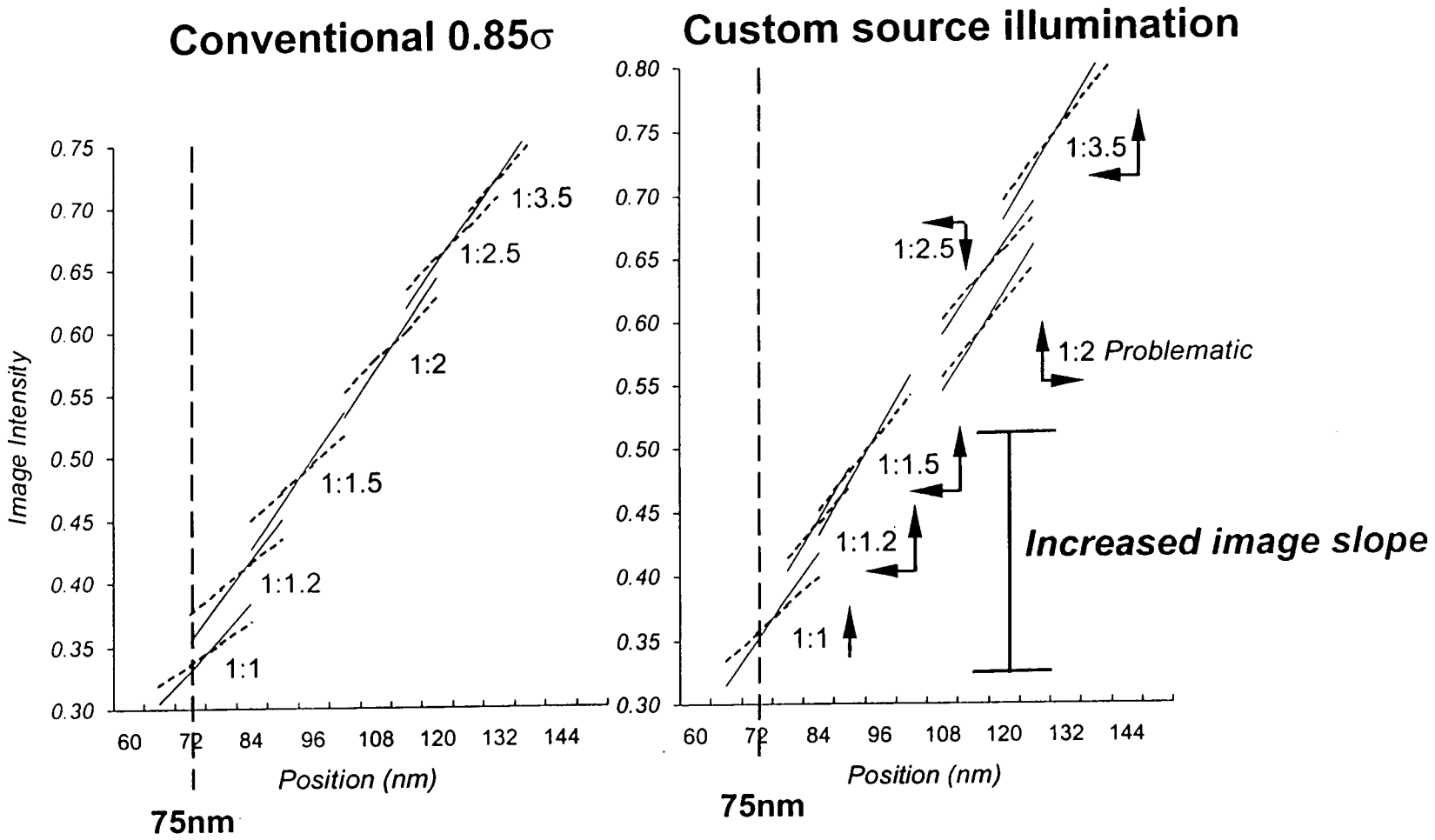
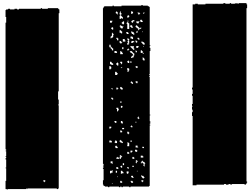


Figure 24. Illumination combined with Gray Bars 150nm 1:1 to 1:3.5

	1:1	1:1.2	1:1.5	1:2	1:2.5	1:3	1:3.5
Line bias (nm)	-	-	-	-	-	10	20
Bar transmission	-	0.5	0.5	0.5	0.5	0.5	0.5
Space design *[space/bar/space] (nm)*	-	[65/50/65]	[83/60/83]	[80/140/80]	[88/200/88]	[108/225/108]	[143/220/143]



1:1 space intensity

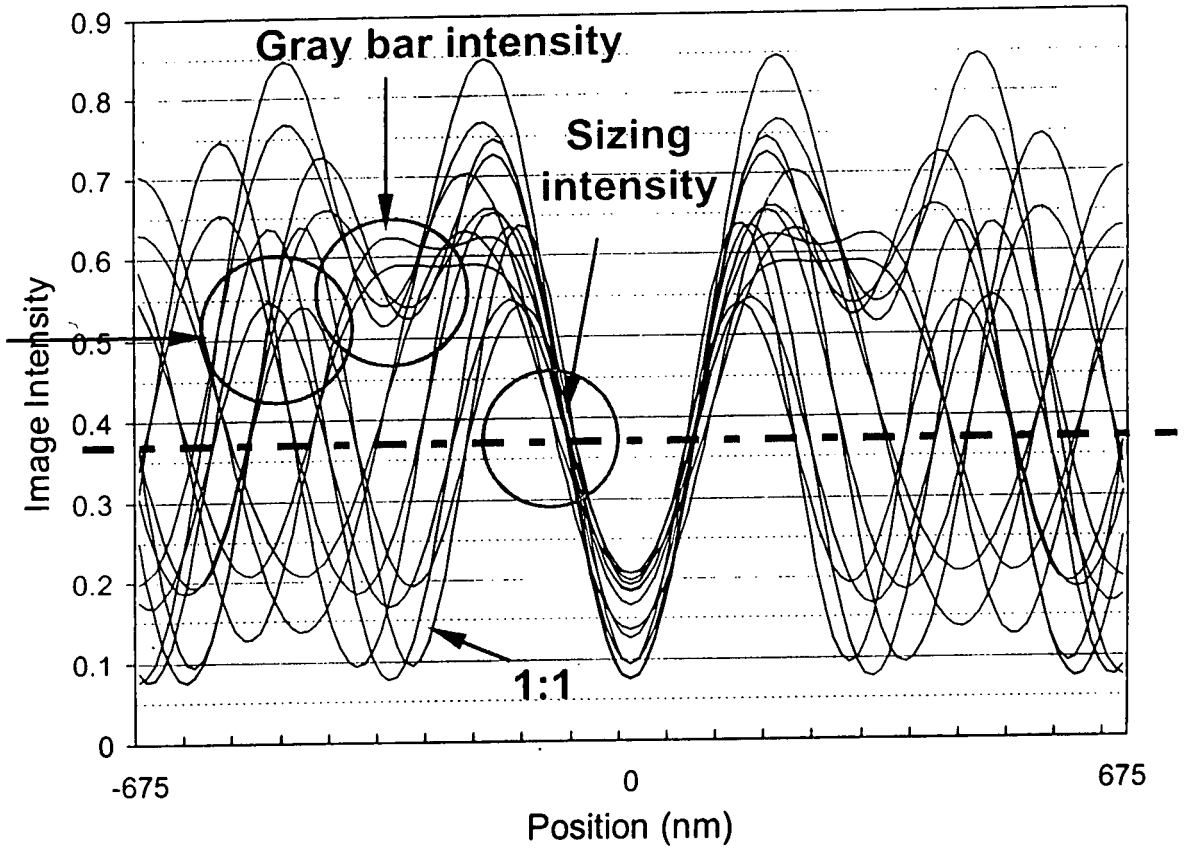


Figure 25. Solving for CD / Intensity inflection

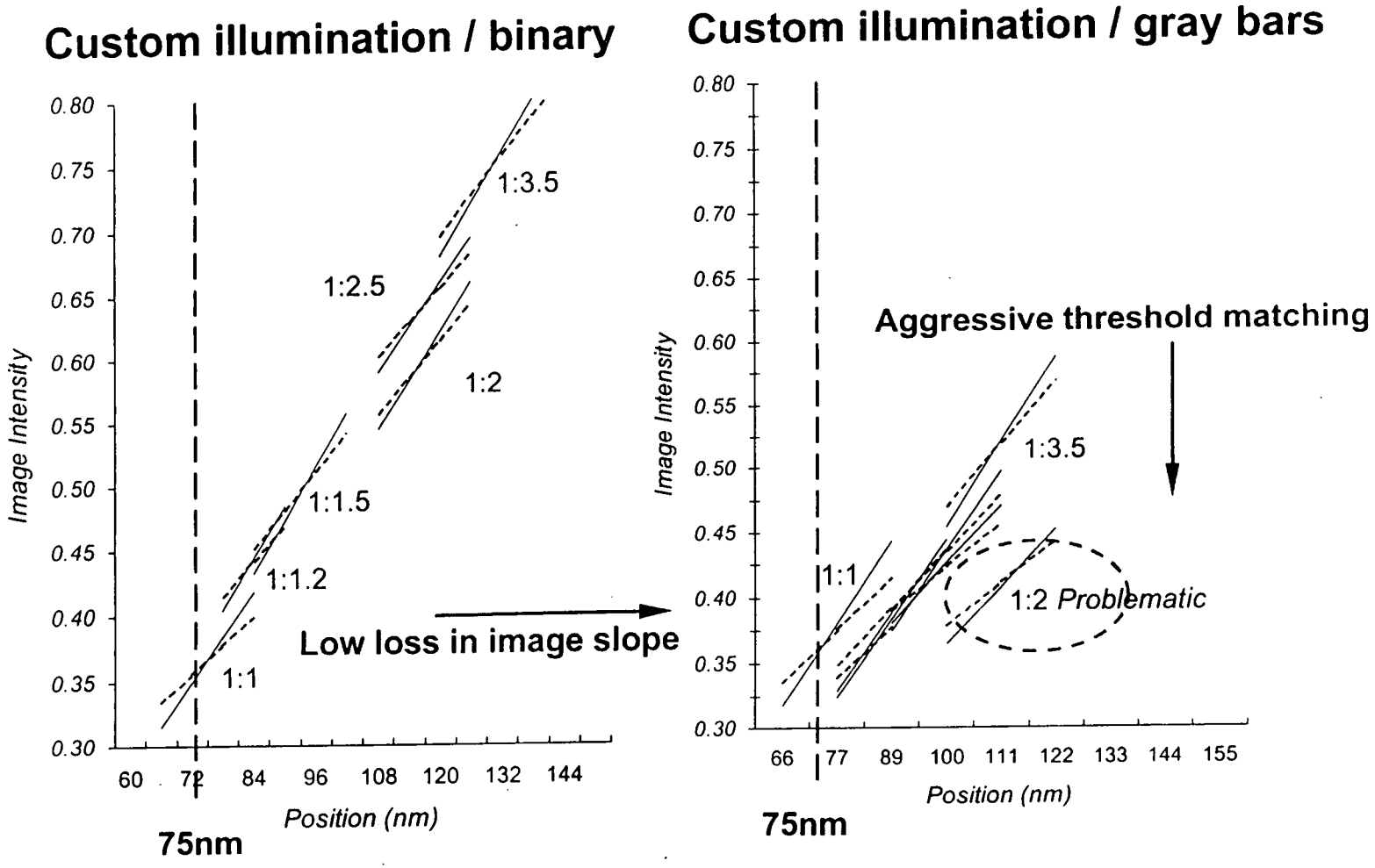
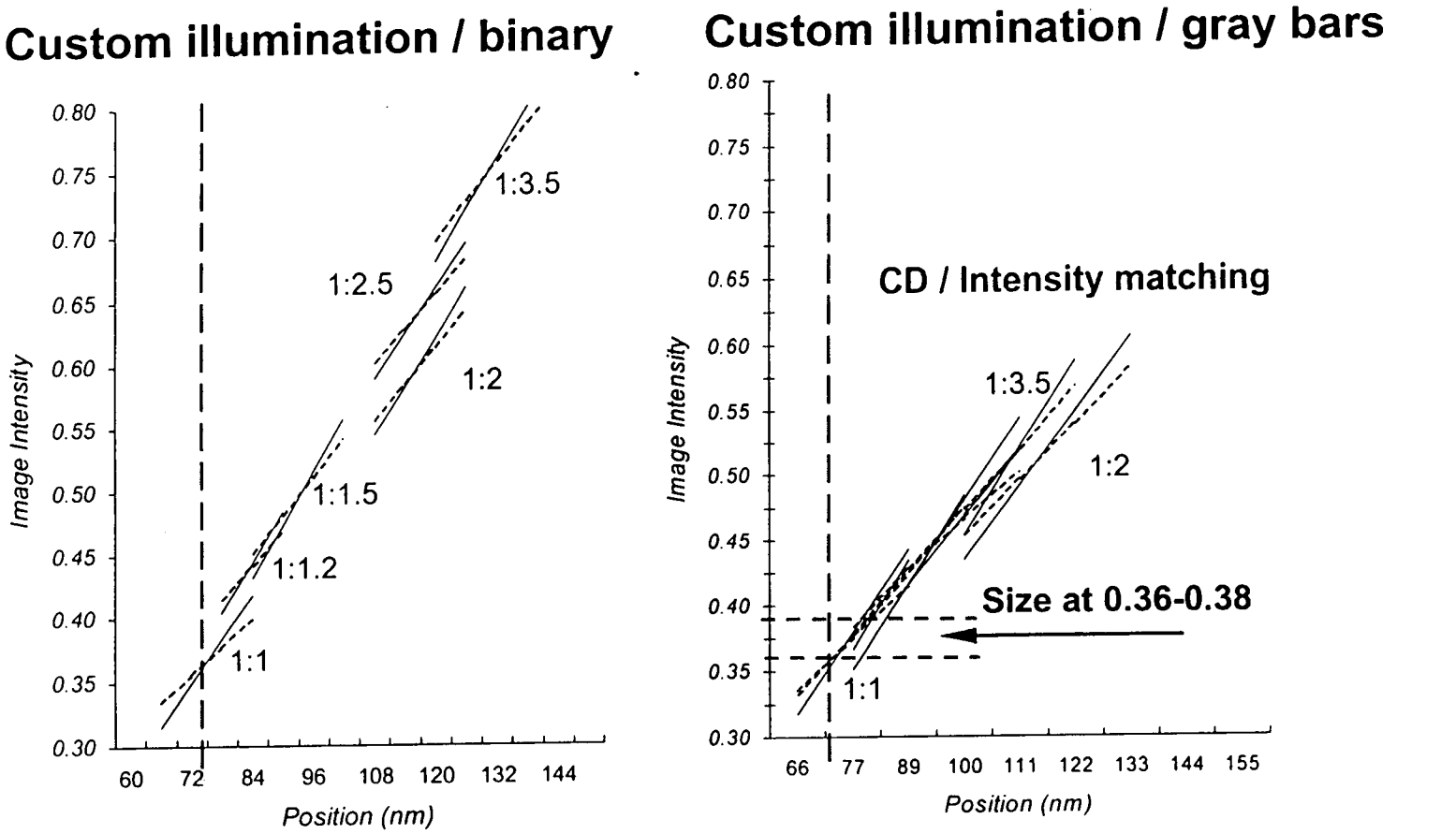


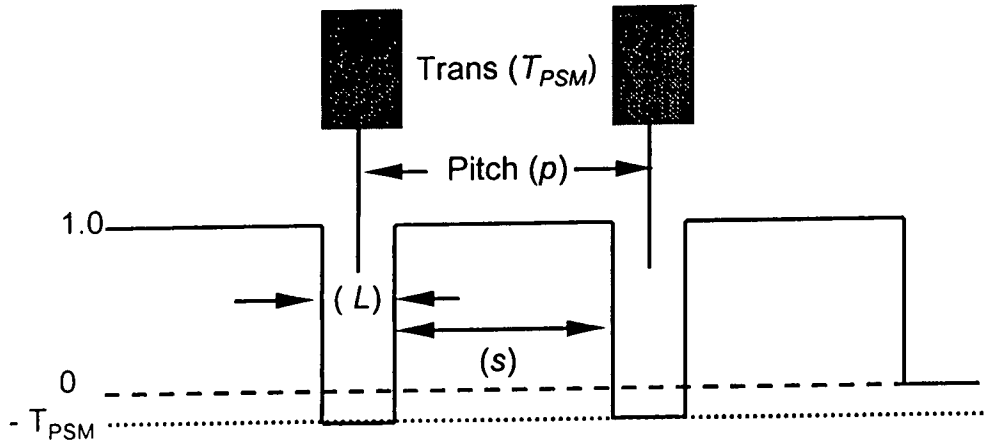
Figure 26. Solving for CD matching



	1:1	1:1.2	1:1.5	1:2	1:2.5	1:3	1:3.5
Line bias (nm)	-	-	-	-	-	10	20
Bar transmission	-	0.5 dots	0.5 dots	0.5	0.5	0.5	0.5
Space design *[space/bar/space]* *(nm)*	-	[65/50/65]	[75/75/75]	[120/60/120]	[113/150/113]	[120/200/120]	[143/220/143]

Figure 27. Mask E-field and diffraction energy for AttPSM

AttPSM mask



$$|\text{Mag.}|_{\text{zero order}} = [1+T](s/p) - T$$

$$|\text{Mag.}|_{\text{first order}} = [1+T]\left|\left(\frac{s}{p}\right)\text{sinc}\left(\frac{s}{p}\right)\right|$$

$$|\text{Mag.}|_{\text{second order}} = [1+T]\left|\left(\frac{s}{p}\right)\text{sinc}\left(\frac{2s}{p}\right)\right|$$

Pupil filtering

Pupil filtering is a function of illumination and NA

$$|\text{Mag.}|_{\text{zero order}} = F_0\,(s/p)$$

$$|\text{Mag.}|_{\text{first order}} = F_1\left|\left(\frac{s}{p}\right)\text{sinc}\left(\frac{s}{p}\right)\right|$$

$$|\text{Mag.}|_{\text{second order}} = F_2\left|\left(\frac{s}{p}\right)\text{sinc}\left(\frac{2s}{p}\right)\right|$$

Figure 28. Fast ImageSolver